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Inertial Confinement Fusion Program Plan

FY 1997 - FY 2006

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TABLE OF CONTENTS

I. INTRODUCTION

Program Purpose, Mission and Goals

High energy density physics

The mission of the U.S. ICF Program is twofold: 1) to address high energy density physics issues for the science based stockpile stewardship program, and 2) to develop a laboratory microfusion capability for defense and energy applications. In pursuit of this mission the ICF Program has developed a state-of-the-art capability to investigate high energy density physics in the laboratory. The near term goals pursued by the Program in support of its mission are: a) demonstrating ignition in the laboratory, and b) expanding the Program's capabilities in high energy density science. The National Ignition Facility (NIF) is a cornerstone of this effort. The primary mission of ICF is for defense applications. ICF research will also provide critical information for the development of inertial fusion energy (IFE).

ICF and Stockpile Stewardship

By Presidential directive and act of Congress (P.L. 103-160), the Department of Energy was directed to "establish a stewardship program to ensure the preservation of the core intellectual and technical competencies of the U.S. in nuclear weapons." This science-based stockpile stewardship approach compensates for the loss of nuclear testing and will maintain confidence in the safety and reliability of the U.S. nuclear weapon stockpile through reliance on scientific understanding and expert judgment.

Facilities, experiments, calculational techniques, and expertise

ICF contributes to the nation's stewardship goals in several ways. First, the ICF Program provides the facilities and capabilities needed to study many of the basic and applied science issues underlying stockpile stewardship. As an example, more than 2000 weapons physics experiments have been carried out on ICF facilities such as the Nova laser at LLNL, the Saturn accelerator at SNL, and the Trident laser at LANL. Second, experiments on ICF facilities will play an important role in the benchmarking of advanced weapons simulation codes being developed by the core nuclear weapons program and the Accelerated Strategic Computing Initiative (ASCI) to assess the reliability and effects of aging of weapons in the stockpile. Third, calculational techniques developed by the ICF Program to model high energy density phenomena may be used in these new simulation codes. Fourth, carrying out state of the art high energy density physics experiments will help retain the high quality of scientific and technical expertise necessary for national security.

Program Facilities and the National Ignition Facility

Drivers enable high energy density physics experiments

The program carries out high energy density physics experiments using laser and pulsed power drivers. The laser facilities include Nova, Omega, Nike, and Trident at Lawrence Livermore National Laboratory, University of Rochester (Laboratory for Laser Energetics), Naval Research Laboratory, and Los Alamos National Laboratory, respectively. The Particle Beam Fusion Accelerator II (PBFA II) and Saturn pulsed power facilities are located at Sandia National Laboratories. General Atomics develops and fabricates many of the targets for the above experimental facilities. In addition to these facilities, a parallel theoretical and modeling capability is in place at each of the above laboratories (with the exception of General Atomics).

A key element of future program efforts is the National Ignition Facility (NIF). In addition to providing the means to demonstrate laboratory ignition, NIF will produce experimental conditions much closer to those in a nuclear weapon than can be obtained in present ICF Program facilities. NIF is thus central to the program for satisfying its stewardship responsibilities.

Program Guiding Principles

The set of general guiding principles below will guide program planning for the next several years (note these are not in prioritized order):

- Continue the target physics and technology development activities to increase the confidence in demonstrating ignition on the NIF and minimize the time to ignition after NIF is complete. Assess the utility of both indirect and direct drive for NIF ignition experiments and a future high yield capability.
- Expand the program's capabilities and knowledge base in high energy density science to maximize the ability of ICF personnel and facilities to address stockpile stewardship issues. The ICF Program will be judged based on its contributions to stockpile stewardship.
- Develop the laser, optic, and target chamber area technologies necessary for the NIF to achieve its cost, schedule, and performance goals.
- Maintain a modest but definite effort in advanced driver development and systems applications for a future high yield facility beyond the NIF.
- While relying on three defense laboratories for the program leadership, continue to work with universities and industrial collaborators so as to increase their roles in high energy density science and to enhance the intellectual vitality of the subject.

II. HIGH ENERGY DENSITY SCIENCE IN SUPPORT OF STOCKPILE STEWARDSHIP

Applied problems exercise complex problem-solving methodologies

The ICF Program has specific applied goals which are tied to developing an understanding in specific areas of high energy density science. Examples of these goals include understanding certain performance aspects of a nuclear device or demonstrating laboratory ignition. Applied problems are characterized by the presence of numerous and simultaneously important physical phenomena. These complexities have led the weapons design program to rely heavily on advanced simulation codes. A similar situation is true for ICF. The importance of ICF to the nuclear weapons program derives from the common interest in high energy density science and the methodology (basic and applied experiments whose analysis relies heavily on computer simulation) used in pursuing applied goals.

High Energy Density Science Common to Inertial Fusion and Weapons

The ICF Program has made and will continue to make significant contributions in all areas of high energy density science relevant to stewardship, including the following:

- **Hydrodynamics**. The study of the hydrodynamic properties of high energy density matter is crucial to understanding issues such as nuclear performance and inertial confinement fusion implosions. Of particular importance are hydrodynamic instabilities, which can disrupt the normal motion of material and thus prevent a desired high energy density configuration of matter from being produced.
- **Atomic physics and radiative properties**. Indirectly driven ICF targets and nuclear weapons secondaries are both driven by x-ray emission arising from the hohlraum and the primary explosion, respectively. The study of x-ray generation, transport, and the coupling of x-ray energy with matter is directly relevant to stewardship.
- **Material Properties and Equations of State**. The temperature and density conditions attained during nuclear weapon explosions and laboratory high energy density experiments are the most extreme on earth. Understanding materials under these conditions is essential to demonstrating laboratory ignition and addressing key weapons physics issues.
- **Plasma physics**. Of particular importance to laboratory high energy density physics experiments is the interaction between the driver (laser or light ion) energy and the plasma resulting from the interaction of this driver with a given target. Plasma instabilities can reduce the amount of driver energy coupled into the system. While not directly relevant to weapons, consideration of plasma physics phenomena is often necessary in the design of high energy density laboratory experiments.

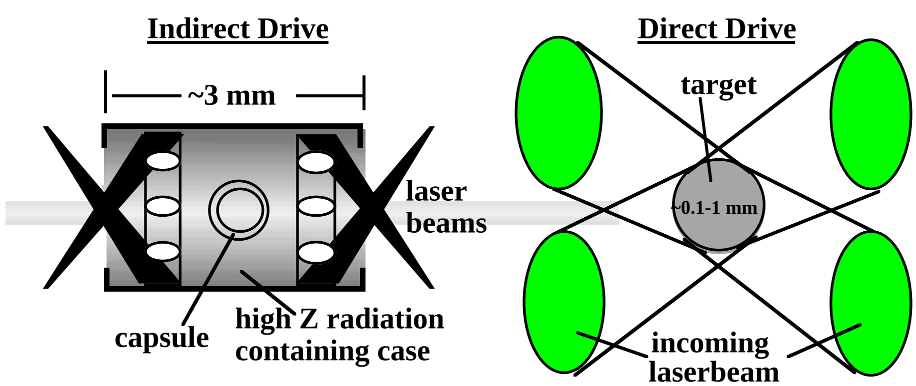
Applied High Energy Density Science Problems: I. Laboratory Ignition

Ignition is a major goal of the NIF

A laboratory ignition experiment will involve compressing a mm-scale capsule 20-40 fold in radius by either x-rays ("indirect drive") or direct irradiation ("direct drive"). Ignition is a major goal of the National Ignition Facility (NIF). The extensive indirect-drive physics data base accumulated to date has given the Program good confidence that NIF indirect-drive ignition experiments will be successful. With respect to direct drive, the physics data base required to prove the feasibility of this concept will be generated over the next few years. Direct drive on NIF has the potential to produce gains 3-8 times higher than for indirect drive. These higher yields would enhance the stewardship applications of NIF; thus, the NIF will be capable of direct drive operation.

Demonstration of ignition in the laboratory will rely on adequate understanding in four major areas of effort: hydrodynamics, drive symmetry and energetics, plasma physics, and ignition target design. The status and planned work for direct and indirect drive are described below.

Indirect and direct drive



Indirect Drive

Robustness of ignition design is near-term goal

The state of knowledge in the major areas necessary for ignition has been reviewed by a number of advisory committees and was found sufficient to proceed with the NIF preliminary design, which is in progress. Research over the next few years is aimed at increasing confidence in demonstrating laboratory ignition and minimizing the time to achieve it. Most experiments will be done on Nova and Omega, with supporting work at Trident. The indirect-drive ignition program - culminating in a NIF ignition demonstration - has and will continue to be a national collaborative effort. All laboratories participating in the ICF Program have made significant contributions to the indirect-drive ignition program.

Sandia National Laboratories' PBFA Z accelerator will also provide important data for the indirect-drive ignition program. This facility, which builds on the recent demonstration of record x-ray power production from the Saturn accelerator in a z-pinch implosion, will provide a source of intense x-rays for shock physics and other studies relevant to stockpile stewardship, including ignition on the NIF.

Details of these experiments are contained in the Program Implementation Plan. Figure 1 shows a timeline of planned effort and major milestones. The effort is organized as follows:

Hydrodynamics. Problems to be studied on Nova and Omega include the effects of convergence on instability growth, studies of capsule fabrication defects, the effects of "beam phasing" (see below) on implosions, and assessment of novel techniques for instability mitigation. Equations of state for capsule materials, shock timing measurements, and hydrodynamic instabilities will be studied on PBFA Z.

Drive symmetry and energetics. Further studies of gas-filled hohlraums (the baseline design used for NIF) will continue in order to confirm understanding of relevant physics issues. Control of time dependent drive symmetry in NIF hohlraums relies on spatially separating the laser input energy into two pieces or "cones" of independent temporally shaped pulse. This technique for controlling drive symmetry is known as "beam phasing." This concept will be studied in experiments on Nova and Omega. The effects of beam smoothing, using smoothing by spectral dispersion (SSD), will also be assessed.

Plasma physics. Further experiments will be carried out to assess the laser energy and intensity regimes that are achievable before plasma instabilities result in excessive loss or scattering of laser energy input to the hohlraum.

Ignition target design. Continuing work on NIF target design will focus on targets that are increasingly robust and thus more likely to ignite. The effects of symmetry, hydrodynamics, and plasma physics constraints will be incorporated into ignition target designs as new results appear. Improved hydrodynamics, atomic physics, and other modeling capabilities will be incorporated in Program simulation codes as they become available.

Direct Drive

Direct drive ignition feasibility

The major goal of the direct drive program over the next few years is to assess the feasibility of direct drive ignition on NIF. This program has two components: (1) integrated spherical implosions of NIF-like pellets; and (2) separate tests of individual physics issues. Implosion experiments will be carried out at Omega using the available 60 beams, which provide the required drive symmetry. Physics constraints arising from hydrodynamics and plasma physics will be studied in planar geometry using primarily Omega and Nike, with some work being done at Nova and Trident. With direct drive, laser light strikes the capsule directly, and thus sufficiently smooth laser beams are essential. Assessing the level of laser beam smoothness required for ignition will be a major theme of the direct drive program.

Evaluating the feasibility of direct drive on NIF involves the four areas listed above for indirect drive. Direct-drive specific issues include the following:

Hydrodynamics. Planar Rayleigh-Taylor instability experiments similar to those done previously for indirect drive will be carried out on OMEGA, Nike, and Nova. These experiments will determine the hydrodynamic stability constraints and associated laser uniformity requirements for direct drive ignition. In particular, these experiments will determine the feasibility of direct drive ignition on NIF. An important feature of the OMEGA program is that cryogenic implosion experiments are planned for 2000. These implosions will test direct drive physics issues and are also important to test engineering concepts for the NIF cryogenic system. Cryogenic foil experiments planned as part of the hydrodynamics and equation of state campaigns on Nike and Nova will also add to the Program's cryogenic target capabilities. The use of "foam buffering" and controlled radiation preheat to mitigate instability growth will also be studied.

Drive symmetry and energetics. A critical issue for direct drive is to assess the effects on capsule performance of laser beam nonuniformities "imprinted" on the capsule outer surface. Experiments on Omega will determine the level of beam smoothing that can be achieved with glass lasers and the constraints that this places on NIF direct drive ignition target design. Important corroborating information will also be obtained using the Nike KrF laser, where the effects of varying levels of beam smoothing on capsule hydrodynamic instability will be examined.

Plasma physics. The interaction of incident laser light with the capsule can also lead to excessive scattered laser light. This scattering process places an upper limit on the acceptable laser intensity on a capsule. Basic plasma physics experiments on Omega will assess this topic.

Ignition target design. A preliminary design for a direct drive NIF ignition target has been proposed by the University of Rochester, and assessment of this target will continue. Design work will continue at LLE, NRL, LLNL, and LANL to enhance these target designs and incorporate results from ongoing experiments. Improved hydrodynamics, atomic physics, and other modeling capabilities will be incorporated in simulation codes as they become available; a particular example of this is a state-of-the-art atomic physics package under development at NRL.

Advanced Concepts

Z pinches

In addition to the NIF-related ignition program defined above, work will continue on several "advanced concepts." The heating of hohlraums with the x-ray radiation from a z-pinch pulsed power source has been demonstrated on Saturn. This work will continue on PBFA Z, where symmetry and other issues will be evaluated so as to assess the suitability of z-pinches as a driver for indirectly driven high performance capsule implosions. Details of these experiments are outlined in the Program Implementation Plan.

Fast ignitor

The "fast ignitor" scheme for obtaining ignition or high gain will also be studied. In this scheme a long pulse laser drives a conventional implosion and produces a compressed target configuration, which is then ignited by a high intensity pulse from a short pulse laser of about 10-12 psec. duration. A short pulse petawatt (10^{15} W) laser capability recently demonstrated on Nova will be used to study the basic physics issues underlying this concept.

Applied High Energy Density Science Problems: II. Weapons Physics

Laboratory experiments test weapons physics issues

Weapons physics and related stockpile stewardship experiments carried out on ICF facilities are collaborative efforts carried out by ICF and weapons program personnel. The role played by the ICF Program is generally twofold: (1) to expand the range of high energy density plasma conditions (hohlraum temperature; plasma lifetime, density, and temperature) accessible in the laboratory, and (2) to define new experimental geometries, techniques, and diagnostics that facilitate stewardship experiments. Laboratory experiments to test particular weapons issues are then carried out in collaboration with weapons program scientists.

Weapons physics scaling

Similar to ignition physics, weapons physics experiments on ICF facilities involve the study of both basic and applied high energy density science problems. Some of these experiments will be proof of principle efforts for larger scale experiments on future ICF program facilities that will be carried out in a regime more comparable to weapon conditions. In particular, the scaling of these experiments to NIF and potential future pulsed power facilities is of high priority, as these capabilities will be required in the near term to maximize the utility of the ICF Program to stockpile stewardship.

Plans for fundamental high energy density science research relevant to weapons include:

Hydrodynamics. Planar experiments on Nova, Omega, and Nike will investigate the transition to turbulence. The formation of jets will be studied using hemispherical and other targets.

Atomic Physics and Radiative Properties. Measurements of mid-Z material opacity will continue on Nova and PBFA Z, and begin on Nike. Preparatory work for NIF opacity experiments such as x-ray backlighter development will also continue. New atomic physics modeling capabilities are under development at LLNL, LANL, and NRL.

Material Properties and Equation of State. Methods for measuring on- and off-Hugoniot equations of state to the few percent accuracy required to differentiate between theories will be developed. The use of flyer plate techniques to achieve very high pressures (pressures near ~ 1 Gbar have been observed to date) will be explored.

Plasma Physics. Plasma physics issues relevant to important goals, such as the achievement of hohlraums with temperatures greater than 300 eV, will be investigated.

Computational Physics. The ICF Program will continue development of advanced three-dimensional simulation codes, as described further below.

Specific applied problems to be considered include:

High temperature hohlraum development. Hohlraums with drive temperatures well in excess of 300 eV are of interest to the weapons program for hydrodynamic studies and other experiments; efforts to develop such radiation environments will be carried out on Nova.

Radiation flow. Experiments to investigate radiation flow applicable to weapons will be done on PBFA Z, Saturn, Nova and Omega. One- and two-dimensional experiments will be carried out. The large energy capabilities of pulsed-power devices, which allow them to drive relatively large volumes for long periods, makes them well suited for such experiments. Hohlraums driven by long laser pulses are also under study.

Applied hydrodynamic studies. Hydrodynamic experiments will be carried out on Nova, Omega, Nike, and PBFA Z to assess the effects of gaps, cracks, and other features present in an aging stockpile. Many of these experiments will be used to benchmark simulation codes under development by the Accelerated Strategic Computing Initiative (ASCI) to assess aging and other effects on weapons performance.

Nuclear weapons effects testing. Pulsed-power facilities have long been used by the radiation effects community to assess x-ray damage effects, and these efforts will continue. Laser-based effects testing has shown significant promise over the past few years and the capability will continue to be developed.

Use of ignition targets. The uses of NIF ignition capsules for effects testing and the study of burn-related issues in weapons will be investigated.

Short pulse laser applications. The uses of the petawatt laser (developed for the fast ignitor project) for producing high energy density plasmas of interest to the weapons program will be studied. The petawatt laser may also be important to ignition related issues should it allow the yield of a NIF ignition target to be increased.

Other Applied High Energy Density Science Problems

ICF facilities will also be used to address other high energy density physics issues, such as laboratory astrophysics and the strength of materials under conditions of extreme temperature and density. Much of this work will occur in collaboration with university and industrial researchers. The ICF Program is committed to increasing the presence of non-ICF Program personnel in the high energy density physics community so as to make the Program's capabilities available to researchers across the nation and to utilize, at the same time, the unique contributions that can be made by these outside researchers.

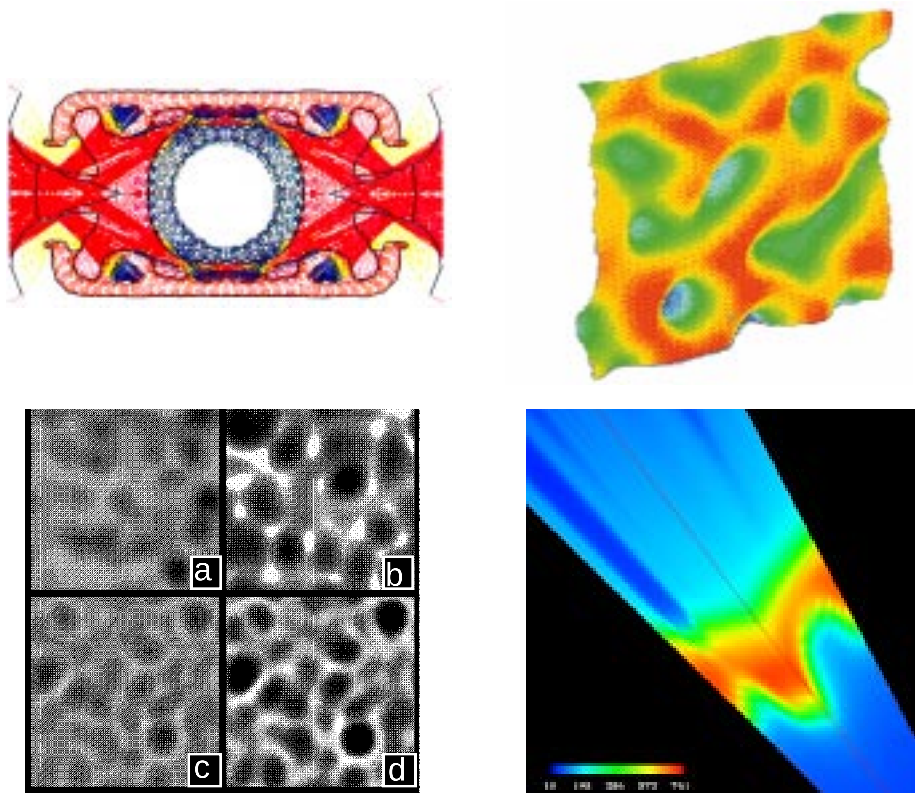
Code Development

The ICF Program has maintained a vigorous code development program since its inception. The numerous physical processes important at high energy density have motivated the need for sophisticated target design codes. The physical processes involved are qualitatively similar to the nuclear weapons program due to the commonalities in the underlying science. The best known simulation code developed by the ICF Program is the two-dimensional LASNEX code, used at LLNL, LANL, and SNL. Three-dimensional codes for plasma physics research and other specific purposes have also been developed. The program also develops codes to address specific target physics and driver design issues.

3-D design code

The main effort in ICF code development over the next five years will be aimed at developing a robust three-dimensional design code for use in laboratory (ignition and weapons physics) target design. This development effort will also contribute significantly to creation of new robust three-dimensional nuclear weapon design codes. These efforts will be carried out at LANL, LLNL, SNL, in collaboration with ASCI. The benchmarking of three-dimensional codes via NIF experiments, particularly with ignition, will be an important part of the ICF Program's contribution to stockpile stewardship. A major goal of this work in addition to creation of a new design code itself will be to make improvements in the underlying physics "packages" used in these codes. These new packages will be tested in experiments on Program facilities.

Code simulations



Integrated calculation for an NIF ignition target, including laser energy deposition, hohlraum radiation field, and capsule implosion (upper left; courtesy, LANL). 3D ablatively driven planar foil simulation (upper right; courtesy, UR/LLE). X-ray pictures at two time intervals (a, b) and equivalent 3D computer code predictions (c, d) of plastic foil showing imprinting by illumination with nonuniform laser (lower left; courtesy, NRL). Density contour profiles of NIF capsule implosion with initial multimode perturbations on inner ice and outer ablator surface (lower right; courtesy, LLNL).

Radiation-hydrodynamics code

Significant radiation-hydrodynamic code development efforts related to direct drive will also continue at LLE and NRL. In particular, these laboratories will develop codes capable of three-dimensional simulation of directly driven implosions. When appropriate NRL and LLE will collaborate with the weapons laboratories on development of specific physics packages for use in next-generation target design codes.

Target Fabrication

Achievement of the program's stockpile stewardship and ignition goals requires significant target fabrication technology development to make the necessary target physics experiments possible. For weapons physics experiments, both direct and indirect drive schemes are used to drive appropriately scaled versions of specific weapons problems, material samples to measure shock speeds or opacity, or deliberately perturbed weapons material samples.

Target fabrication for ICF has three main thrusts: noncryogenic target development and characterization; cryogenic layering research; and cryogenic systems engineering. The basic design of all NIF ignition targets consists of an annular DT ice layer contained in a plastic or beryllium capsule. Several other ablator coatings are also being pursued. For indirect drive, the capsules are enclosed in hohlraums. Capsules from a variety of materials must be developed with sufficient sphericity, wall uniformity, and surface smoothness at all scale lengths, and must be fillable with DT fuel and diagnostic tracer gases.

NIF-scale beryllium hemishellls

Beryllium capsules offer potential improvements in implosion performance over polymer shells because of their reduced susceptibility to Rayleigh-Taylor instabilities. In addition, they have sufficient material strength to contain the required high pressure DT fill at room temperature and offer improved ice layer concentricity due to the higher thermal conductivity of Be (courtesy, LANL).

Cryogenic layering

Methods to form and characterize smooth and symmetric DT ice layers on the interior of these capsules are being developed. The surface of the DT layer in an ignition capsule must be sufficiently smooth so as to avoid breakup of the target by hydrodynamic instabilities during implosion. The required smoothness as defined via computer simulations of NIF targets has been demonstrated experimentally for the case of indirect drive in stand-alone layering experiments. Auxiliary heating via laser or microwave radiation has been shown to reduce the DT surface roughness further and will provide an increased margin for ignition. Research in this area will concentrate on a) developing the larger capsules required for direct drive ignition, and b) fielding actual indirect- and direct-drive capsules with the required DT layer smoothness.

Cryogenic target capability

A cryogenic capsule fielding system is being developed for the Omega laser by General Atomics in collaboration with Los Alamos and the University of Rochester. Scheduled for delivery by 2000, this system will allow important cryogenic implosion experiments and will also provide important experience relevant to the design of a NIF cryogenic target system, which is scheduled to begin engineering design in 2001. In preparation for the target system engineering concept, development and prototyping will occur from 1997-2001.

Diagnostic development

High spatial and temporal resolution measurements

A key technology for high energy density science experiments is the ability to make measurements of transient high energy density matter at high spatial and temporal resolution (typically a few microns and a few picoseconds, respectively). Neutron emissions, as well as x-ray and optical emissions from ICF targets, are monitored for diagnostic purposes. The continuing development of state-of-the art diagnostic equipment capable of making such measurements has been essential to the success of the ICF Program to date and will continue. Development of such diagnostics is also critical to the stockpile stewardship program. Activities in this area have been a major source of ICF Program "spin-offs" such as the micro-pulse impulse radar developed at LLNL. The diagnostic development area is also fertile ground for collaborations of Program personnel with outside researchers. Future diagnostics to be developed include a) x-ray laser diagnostics of plasma conditions, b) capsule implosion diagnostics based on tertiary thermonuclear products, c) laser based measurements of shock transit times through materials, and d) Thomson scattering to measure hohlraum densities and temperatures.

Relation to other Defense Programs Activities

Accelerated Strategic Computing Initiative (ASCI)

The ICF Program will contribute to the development and testing of the next-generation nuclear design codes under development by the ASCI and core programs in several ways. First, ICF Program facilities, especially the NIF, will provide a significant portion of the laboratory experimental capability that will be used to validate the accuracy of the assumed physics in these codes. Experiments carried out on Program facilities will also serve to test the use of these codes in simulating integrated phenomena such as hydrodynamic instability effects arising from imperfections due to aging or manufacturing. Second, ICF and ASCI computational physicists will work together collaboratively on many aspects of ASCI code development - to benefit from the ICF Program's long history in developing large scale radiation-hydrodynamic simulations. Third, the paradigm of simulation and experimental testing to be followed under the stockpile stewardship program is identical to that followed by the ICF Program over many years, which makes the ICF Program a natural component of the overall stewardship program.

Strategic management activities

When necessary, particular technologies developed by the program will be used to address stockpile management issues. Several examples of this have already taken place; these are not discussed here because of classification.

Domestic Collaborations with Researchers Outside the ICF Program

Grants program

ICF Program facilities have accommodated experiments by outside agencies, corporations, and universities. The National Laser User Facility (NLUF) at the University of Rochester has sponsored research by outside users on Omega since 1979. LLNL, LANL, and SNL have made facility time on ICF Program laser and pulsed power devices available to university and other outside users. A method to increase the support for outside researchers is being developed by the DOE ICF Program in collaboration with the ICF Program laboratories as part of the science based stockpile stewardship program and is expected to be started in FY98. The purpose of this program is to broaden the high energy density science field generally, foster independent researchers in high energy density science, provide additional technical contacts for laboratory scientists, and train students for careers in the field.

International Collaborations

The ICF Program has worked with other laboratories abroad where appropriate. A formal DOE/French Commissariat a l'Energie Atomique (CEA) agreement has resulted in a very productive collaboration among LLNL, LANL, and the CEA in the areas of NIF laser technology development and target physics. ICF Program scientists are active participants in the weapons physics and other activities sponsored under existing treaty agreements with the United Kingdom Ministry of Defense. Individual ICF Program scientists have also collaborated with colleagues around the world, including those in the United Kingdom, France, Japan, and Russia. These activities have benefited the Program by allowing results of other research to be incorporated in a timely and efficient manner. All international activities are reviewed by the DOE before commencing.

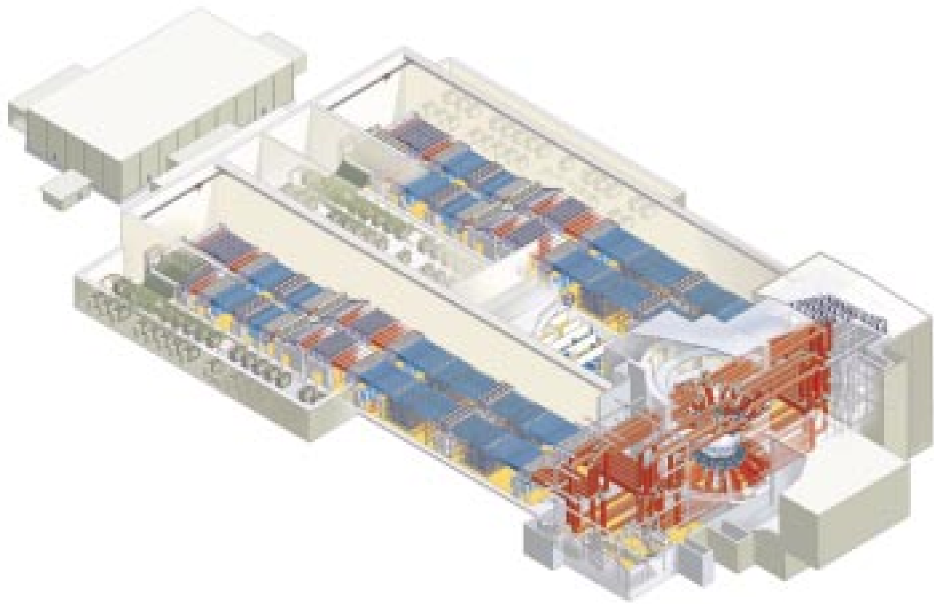
III. THE NATIONAL IGNITION FACILITY (NIF)

Ignition and burn in the laboratory

The National Ignition Facility (NIF) is a congressionally approved $1.1 billion project to build the world's largest laser to demonstrate fusion ignition and burn in the laboratory and provide unique capabilities in high-energy-density physics research necessary for the ICF Program to carry out its stewardship mission. A national community of ICF Program laboratories is participating in the design, construction, and eventual operation of the NIF. The NIF, which is based on advanced glass-laser technology, is designed to have 192 beams and will produce 1.8 MJ of energy at a wavelength of 0.35-µm.

The physics need and mission of the NIF for stewardship has been reviewed by the JASON group and the Inertial Confinement Fusion Advisory Committee (ICFAC), both of whom strongly support the project. The Department of Energy approved Key Decision One (New Start, Oct. 1994). NIF's Title I design will be completed in Fall 1996. Details of the laser design are in the comprehensive NIF Conceptual Design Report (CDR).

National Ignition Facility



As a key element of the stockpile stewardship program, NIF will:

- Demonstrate laboratory ignition and moderate gain.
- Provide data on materials of strategic importance under extreme pressure and temperature conditions.
- Provide data for benchmarking advanced code development.
- Facilitate the development of new and high-quality diagnostic techniques with unprecedented temporal and spatial quality.
- Aid the weapons community in retaining the capability for investigating many weapon-physics issues.
- Provide technological spin-offs and commercialization possibilities in a variety of technological fields, including high-power lasers, optical materials, photonics, and microfabrication.
- Provide an effective means to maintain nuclear weapons competence and capabilities under a test moratorium or ban.
- Define the technical requirements for future defense and energy facilities based on fusion.

Design, Procurement, Construction, Installation & Assembly of Conventional and Special Equipment & Facilities

Mission requirements define specifications

The NIF design criteria are derived from the Program mission as set by DOE and Federal directives and defined by the needs of NIF users and stakeholders. The primary laser and target area specifications are defined by the mission requirements. The laser, optics, target area, and diagnostic technology development required for the NIF is part of the ICF Program.

NIF project

The NIF project consists of seven main Work Breakdown Structure (WBS) elements that physically comprise the facility: conventional facilities, laser system, beam transport, integrated computer control, optical components, laser control and target experimental system. Other WBS elements provide for project management, operations planning, and facility start-up. Conventional Facilities provides the buildings and site infrastructure for the NIF Project. The Laser and Target Area Building (LTAB) will house the laser system and the target experimental system. The laser and laser control systems generate high-power optical pulses, which the transport system delivers to the target chamber. For direct drive, multiple laser beams will be reconfigured to irradiate the target surface uniformly. The target experimental system consists of systems necessary to perform target experiments, such as the target chamber, target emplacement positioner, target diagnostics, and environmental protection systems. The integrated computer control system is a network of computer systems that provides the hardware and software necessary to support full operational activities. Optical components consist of the many large optical elements required for NIF.

Critical Decision Points

Future Critical Decision Points (the former Key Decision Points [KD] are no longer used) are: CD 3-Approve Construction Start (mid FY 97) and CD 4-Approve Start of Operation (end of FY 02). Details of the plans for project execution are given in the NIF Project Execution Plan. Details of the laser design are given in the comprehensive NIF Conceptual Design Report (CDR).

ICF Program Technology Support

The ICF Program will continue the support of laser, optic, and target area technology development required for the NIF that was started in FY 95. These activities are summarized below and detailed in The Core Science and Technology Development Plan for Indirect-Drive ICF Ignition (available from the LLNL ICF Program Office). Successful completion of these activities will reduce risk, improve performance, control cost, enhance reliability, and also provide the technical basis that will be critical to the NIF CD 3 (Approve Construction Start). This program of laser, optic, and target chamber technology development is carried out at LLNL, LANL, SNL, and the University of Rochester.

Laser and Optics Technology Development for the NIF

Laser and optics technology development activities will be carried out through FY98. Much of the work is done in collaboration with the French Commissariat a l'Energie Atomique (CEA) under a DOE-CEA agreement. The timely completion of the laser and optic technology development program is needed to maintain the total NIF cost at the $1.1B level.

Laser technology development

Laser activities cover the development of components and subsystems, including the optical pulse generator, power amplifier, optical switch, frequency converter, pulsed-power system, laser diagnostics, laser alignment systems, and control systems. Laser development includes both component tests and integrated performance tests using the Beamlet laser, a scientific prototype of a NIF beamline located at LLNL. The laser components of NIF are much larger and more densely packed than in previous glass lasers and thus must be prototyped at full scale to ensure the necessary performance, reliability, and ease of maintenance. The Beamlet laser is demonstrating that the required energy output can be achieved in conjunction with the necessary pulse shaping, focal properties and coherence control.

Optics technology development

Optics development has focused on all aspects of producing large-aperture, high-quality optics in large quantities and at reduced cost. These items include (1) laser glass, KDP crystals, fused silica, and high damage threshold coatings; (2) the finishing, testing and characterization necessary to prove the optics meet the demanding specifications, and (3) the cleaning methods to achieve and maintain these optical characteristics during use. The development must be completed in three years because of the long manufacturing time required to produce the large quantity (~6,000) of NIF-required optics. To fulfill the NIF optics requirements, it is necessary to develop many new manufacturing technologies such as continuous melting of phosphate laser glass, rapid growth of KDP crystals, deterministic finishing methods, highly controlled multilayer deposition and laser damage conditioning, and the development of large aperture diffractive optics with complex wavelength-scale surface structures. The development of these new technologies will have ramifications in many other fields and will enhance the U.S. optics industry relative to its international competitors.

Manufacturing Readiness Plan

The optics manufacturing and laser-component-development activities are discussed in the Manufacturing Readiness Plan for the National Ignition Facility, together with an assessment of the risk associated with these developments. This plan was written specifically to address a request from the Secretary of Energy following Key Decision Zero (KD-0). The development activities discussed in the Core Science and Technology Plan are funded solely by the national ICF Program. The Plan also covers manufacturing, facilitization, and component reliability and lifetime testing costs which are included in the NIF project.

Target Area Technology Development for the NIF

First wall and target chamber development

Target-chamber development includes characterizing the effects of the target debris, radiation, and electromagnetic interference from NIF experiments on the target chamber equipment and diagnostics. Target-chamber components include the "first wall" (interior surface of the target chamber, which is exposed to target debris and radiation), target positioner, laser beam dump, the final optics protection, and in-situ tritium and debris cleaning systems.

Diagnostic development

The plasma conditions and neutron yields expected on the NIF will require development of new x-ray and neutron diagnostic hardware and techniques. Many of these new techniques will be tested on the Program's existing lasers and pulsed power facilities. Other engineering development will also be done. A "Joint Central Diagnostics Team," with members from the national laboratories and the University of Rochester, will coordinate NIF diagnostic development activities.

Facility Use Plan

National users' facility

The NIF will be operated as a national users' facility with users including federal laboratories, universities, industry, and, perhaps, foreign participation. A Facility Use Plan is being drafted to accommodate the flexible operation and controls required to accommodate both defense and energy missions. An estimate of the series of experiments to achieve ignition is included. This plan also discusses anticipated experiments for stockpile stewardship, weapons effects, energy research, and basic science.

IV. HIGH YIELD FACILITY DRIVER DEVELOPMENT

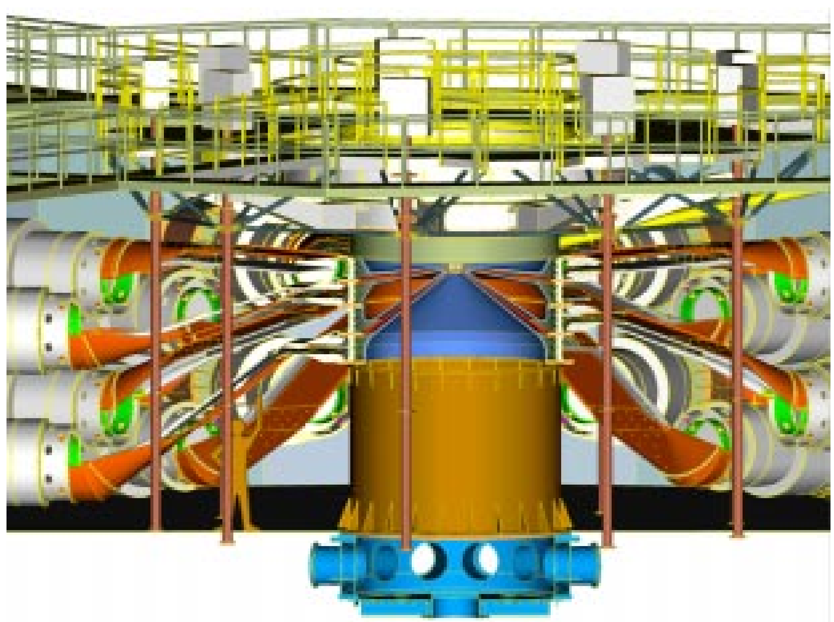
The mission of the ICF Program includes development and utilization of a laboratory-scale microfusion capability for defense and other applications. This program plan therefore addresses the requirements and technology appropriate for a high yield facility. The primary uses of this capability are to provide access to physics regimes of interest in nuclear weapon design, to provide nuclear-weapon-related physics data (particularly in the area of secondary behavior), and to expand an aboveground simulation capability for nuclear-weapon effects. The expected purely fusion yields from such a facility will be several hundred megajoules or more, as compared to the 2-20 megajoules expected from the NIF. Below we describe plans for advanced driver research.

Z pinches

Saturn

As mentioned in Sec. II, in the near term the PBFA II, operating in a z-pinch mode (PBFA Z), will address specific ICF, NIF ignition physics, and weapons physics issues. The PBFA Z experiments, to begin in FY1997, are motivated by the recent demonstration of 0.5 MJ and 85 TW of radiated x-ray energy and power on Saturn. Large (> 6 cc), long-lived (~ 25 nsec) vacuum hohlraums have been heated with z-pinch sources on Saturn, thus demonstrating their utility for weapons physics, ICF, and other stockpile stewardship experiments. A near-term milestone is execution of energy and power scaling experiments on PBFA Z. If the scaling is as predicted, an x-ray yield of 1.5 MJ on PBFA Z could indirectly drive a 2-millimeter-scale ICF target. Assessment of z pinches for high yield will require development of a knowledge base in the ignition physics areas listed earlier (hydrodynamics, drive symmetry, plasma physics, and ignition target design) in a manner qualitatively similar to past and current efforts in laser-based indirect and direct drive ignition physics.

PBFA Z



Light Ions

PBFA X, SABRE

High yield at a high repetition rate requires that ion beams be transported a significant distance from the diode to the target to protect diode hardware and permit voltage-ramped beam bunching. Calculations with 2-D and 3-D codes indicate that the required target symmetry for high yield may be obtained by using an axially focusing, or “extraction.” geometry. PBFA II was converted to such a geometry, referred to as PBFA X, and a lithium ion power of 4 TW was measured on PBFA X in FY 96. Although this ion power is promising and a factor of 20 higher than obtained on the smaller SABRE extraction diode facility, important issues such as beam focusing, ion beam transport, and improving the lithium ion source remain. In particular, increased lithium ion beam current (a factor of two to three higher than attained on PBFA X) is required to study extraction diode physics relevant to ignition and high yield. Accordingly, light ion research in the near term will be primarily carried out on SABRE. The flexibility and ease of use of this smaller facility will facilitate development of the basic understanding required to address the critical issues facing the light-ion beam program.

Heavy Ions

HIF

Heavy ion fusion accelerator (HIF) research is conducted by the DOE Office of Energy Research. It is not part of Defense Programs and is not covered under this plan. Heavy ion accelerators offer the potential of high repetition rate and high efficiencies needed for energy applications. Although HIF oversight is separate, there are common interest areas to ICF. Past collaborations have taken advantage of beam transport methods common with light ions and similarities of HIF target design to laser target design.

The HIF community also is exploring the feasibility of conducting experiments on the NIF that are relevant to heavy-ion fusion. After ignition is demonstrated, the NIF can contribute important data on Inertial Fusion Energy target-chamber issues, including neutron damage, activation, target debris clearing, operational experience and tests of candidate low cost inertial fusion energy targets and injection systems.

KrF Lasers

Nike

KrF lasers are another advanced driver candidate. Because of this laser's good beam uniformity, it is a candidate driver for a direct-drive-based, high-yield facility. In addition, the efficiency and repetition rate of KrF systems make them a candidate for future inertial fusion energy applications. The Program's current KrF laser, Nike, is too small to serve as a prototype for a multi-megajoule system, and there are no plans to build the required 30-100 kJ amplifier. Instead, important KrF laser physics issues relevant to scaling to a megajoule facility will be studied on Nike.

Diode Pumped Solid State Lasers

DPSSL

A diode-pumped solid-state laser (DPSSL) is another possible driver, with potential for low cost in a high-yield application and for inertial fusion energy. Several key developments would make a DPSSL more feasible as a future driver: (1) manufacture of efficient laser-diode pump sources; 2) development of fused-silica target chamber optics to withstand the laser power and target chamber environment; and (3) novel laser gain material with repetitively pulsed compatibility. Lowering diode cost is also an issue, as well as the need to demonstrate DPSSLs at graduated power capabilities that eventually reach future driver needs.